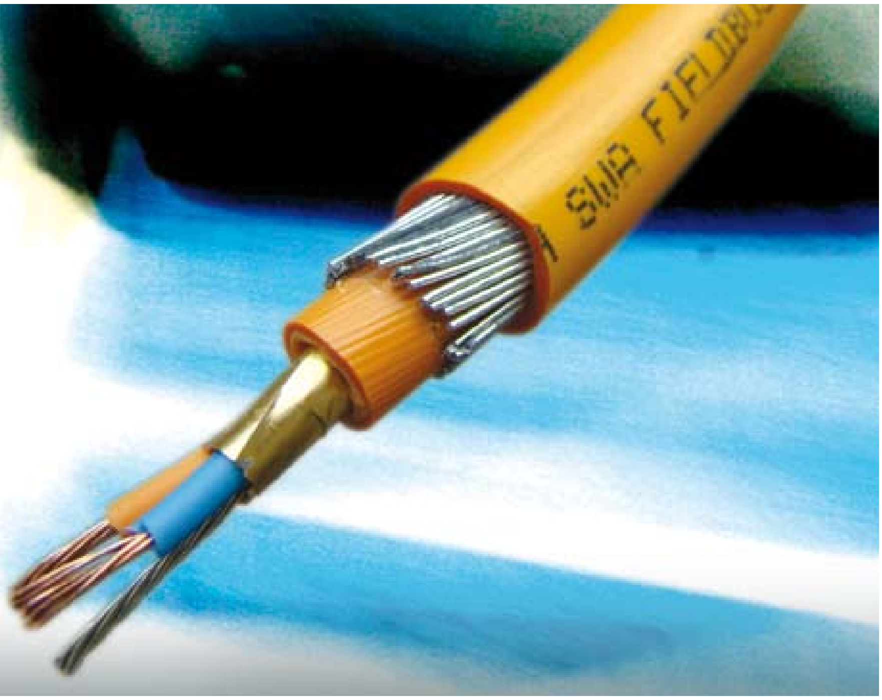
The Fieldbus Years

With 2009 marking the tenth anniversary of the IEC 61158 fieldbus standard, *Jonas Berge* examines the rise of digital for automation and explains why more than one bus protocol became necessary.

Digital technology is pervasive. Music has gone there with CDs and MP3. Cameras, mobile phones, email, high-definition television, photocopiers, musical instruments, car engine controls, and many more are digital. In the same vein, digital bus technology, or "fieldbus" provides improvements for automation and control.

Smart transmitters appeared in the mid-1980s. Because manufacturers used proprietary protocols, distributed control systems (DCS) and handheld communicators were compatible only with devices from the same manufacturer, severely limiting the choice of devices for installation in process industry plants. Similarly, in factories, a PLC only worked with drives from its manufacturer.

Hence, the need for interoperability between devices from different manufacturers was the main driving force for a standard fieldbus. Another driver was the desire by system designers for a multi-drop bus and digital closed-loop control.



Although the consequent effort to create the fieldbus standard – which was officially completed 10 years ago with the release of IEC 61158 – resulted in not one but many protocols commonly referred to as "fieldbus", importantly, it did produce a quantum leap in technology and major international corporations began to implement fieldbus networks.

Enhancements to electronic device description language (EDDL) have made it easy to use fieldbus; the ever more rigorous testing of devices and systems has improved interoperability between the digital bus products from different manufacturers; simpler solutions for hazardous areas have become available; troubleshooting tools have evolved, and engineering guidelines have been established.

After years of refinements, products and systems implementing fieldbus technologies have matured, and many complementing accessories and supporting services have become available

Digital delivers

Fieldbus technology enables connection of multiple devices in parallel on the same pair of wires with each device recognized by a unique address. This reduces the cost of wire and cable trays as well as labor to install trays, lay cable, cut, strip, crimp, label, and connect. Costs are even lower than for remote-I/O.

Variable speed drives and electric actuators are representative of highly attractive and successful bus devices, because they each save many wires. Indeed, devices traditionally requiring multiple wires were the first significant users of bus technology because it meant fewer digital input and output cards and cabinets, and simplified integration – all of which reduce project costs. All fieldbus valves provide continuous actual position feedback and bumpless transfer without additional wiring and input cards, resulting in better process operation.

Fieldbus uses pure digital communication, largely eliminating digital-to-analog and analog-to-digital conversion, and delivering higher resolution and accuracy as a result. Improvements for transmitters, valves, loops, and process units employing fieldbus yield better total plant performance. Moreover, digital values are not distorted and communication errors can easily be detected.

With fieldbus able to drastically reduce cabling demands, devices (like electric actuators) traditionally requiring multiple wires were the first significant users of bus technology.

Fieldbus devices transmit measurements as real numbers in engineering units that are received unaltered on the other end. Since the reported digital process variable (PV) will not be skewed, readings, control, and alarms in the system will be correct. Digital transmitters measure over the full sensor limits and do not saturate at a set range, providing valuable information during abnormal conditions. Moreover, the traditional five-point loop test can be replaced by a simple plausibility check.

When transmitters, controllers, and valve positioners are all digital, passing digital signals between them makes sense. Deterministic communication make possible a real-time closed loop that is digital from sensor to valve. Fieldbus also communicates measurement validity, indicating if a value is good for control, uncertain, or bad due to sensor failure or other problem. Thus, a digital system can distinguish process problems from device problems so that automatic control action is not taken on invalid information. This results in better control and higher availability.

Bus devices can also communicate fast enough to accept firmware downloads online without being removed, making it easy to incorporate new features. With high-speed communication, displays load faster and alerts arrive quicker.

Fieldbus multi-point devices such as high-density temperature transmitters with eight sensor inputs drastically reduce the number of transmitters required, the amount of wiring between the field and control room, and associated labor. For this reason, fieldbus represents a very attractive and successful solution for temperature profiling and similar applications. The multi-solenoid valve bank is another cost-reducing solution by providing several channels in one device.

Advanced diagnostics is an often cited reason for users to go for fieldbus. For instance, two-wire bus devices are permitted to draw sufficient current to drive powerful electronics and software, enabling sophisticated diagnostics such as thermocouple degradation prediction (see *Control Engineering Asia*, Jan-Feb 2009) enabling effective maintenance.

Bus technologies now digitally integrate discrete devices such as on/off valves and electric actuators that traditionally relied on on/off signals and so did not provide feedback communication. Thanks to fieldbus, predictive diagnostics can now come from discrete devices that were not digitally integrated in the past.

Different needs, different buses

On the surface Foundation fieldbus, DeviceNet, Profibus-DP, and Modbus may appear to provide the same benefits, but they are different. Buses for factory automation and process control were designed for different requirements. A single technology could not be agreed upon because the requirements were too diverse, and there was no room for compromise.

So in 1999, eight technologies were included in the same standard – IEC 61158 – which has since grown to include others based on Ethernet. The IEC 61158 standard "slices" the protocols into functional "layers". A profile standard IEC 61784-1 defines how the functional layers are combined to form the actual protocols, grouped into each Communication Profile Family (CPF).

Network	IEC 61784-1 CPF	IEC 61158 Type
Foundation fieldbus	1	1, 5, 9
CIP	2	2
Profibus and Profinet	3	3, 10
P-NET	4	4
World FIP	5	7
Interbus	6	8
Swiftnet	7	6
CC-link	8	18
HART	9	20
Sercos I and II	16	16

Table 1: Protocols part of IEC 61784-1

The main standard debate was around the data link layer (in the ISO seven-layer model), the function that controls which device transmits data and when. The French standard FIP and German standard Profibus represented two opposing philosophies. Since both had strong points, the IEC proposal combined them into one.

The two solutions can be explained with a transportation analogy: FIP operates like a train, transporting data according to a pre-established schedule without traffic jams. Profibus operates like a car, free to go any time provided there is no other traffic. Train-like scheduling is important for PID loops and motion control, but is not necessary for factory automation. Foundation fieldbus is based on the original IEC proposal drawing on both FIP and Profibus to get scheduling but to also allow ad-hoc monitoring and diagnostics.

The PLC world of factory automation and the DCS world of process control have different requirements. Therefore bus technologies were designed to the different criteria required by the two distinct forms of manufacturing (see Table 2).

Network Requirement	Factory Automation	Process Control
Speed	Fast	Moderate
Periodic	Not required	Required
Synchronized	Not required	Required
Intrinsically safe	Not required	Required
Automatic address assignment	Not required	Required
Multi-Master	Not required	Required

Table 2: Factory Automation vs. Process Control bus requirements comparison.

While there were originally eight, now some 20 types of buses are part of the IEC 61158 fieldbus standard. Different technologies compete within each application area: Profibus-DP, DeviceNet, and CC-link technologies for the factory automation market; HART, Foundation fieldbus, and the PA flavor of Profibus for the process control market; and Profinet, Sercos, and others compete for motion control applications.

Need for Speed

Factories have fast moving conveyor belts and machines for packaging, printing, and assembly, requiring response time of just a few milliseconds. Sensors and actuators for these applications are not connected directly to a fieldbus, but use conventional wiring to an I/O-subsystem that in turn connects to the bus. When a state changes, it must quickly be communicated to the PLC. Therefore, factory automation requires high speed communication, and real-time data must not be held up while the bus is idle.

DeviceNet can run as fast as 500 Kb/s and Profibus-DP 12 Mb/s for short distances achieving short bus cycles. Profibus is free-running, meaning that when configuration and other non-real-time data is communicated, the cyclic real-time I/O updates slow down somewhat. But when there is no acyclic communication, the bus is not left idle; updates are done as fast as possible enabling the machines to run faster. The scan is not precisely periodic, but that does not matter in factory automation.

Need for Synch

For process control, a response period of 250 ms to one second is sufficient for closed loops, but the sampling interval must be constant to achieve tight PID control. This is because the integral and derivative terms of the PID algorithm contain a "dt" which is a constant. Therefore the bus cycle must be precisely periodic, that is, the exact same interval every scan. Similarly, input and output sampling in the transmitter and valve must be synchronized with control and communication.

$$OUT = P \times \left(e + \frac{1}{I} \int e\,dt - D \times \frac{dPV}{dt} \right)$$

e = PV-SP

dt = sampling period must be <u>constant</u>

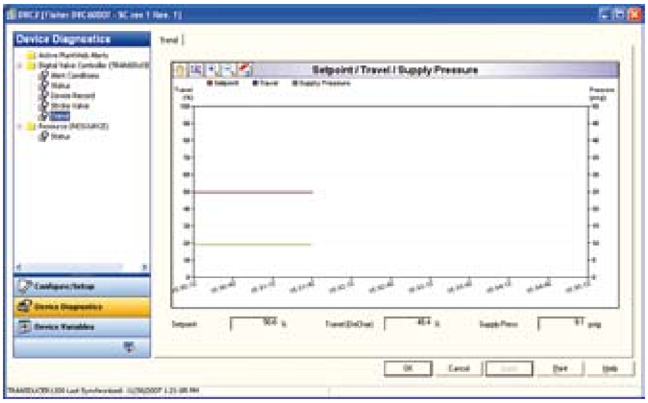
PID control requires a synchronized bus for constant sampling period.

Foundation fieldbus is time synchronized with all devices having an internal real-time clock and operating in synch with the system. This enables a precisely periodic bus cycle and sampling period, called macrocycle. Scheduling automatically created by the system ensures that function blocks are executed and real-time data communicated in the right order at exactly the right time, synchronized from transmitter to valve for optimum PID control.

Periodic real-time communication takes place in dedicated time-slots that are separate from the time-slots for non-real-time communication for configuration and monitoring so as to not interfere with real-time data. Foundation fieldbus devices report diagnostics like alarms, up to the system and included in the system log. For efficiency, reporting is by exception – that is, only when there is a change of state. Device field diagnostics are prioritized so that the system can deliver it to the right person, without a flood of alarms.

Need for organization

With hundreds or thousands of field instruments in a process plant coming in physical contact with the process, typically outdoors, exposed to freezing cold, sweltering heat, sea spray, corrosion, vibration, and shock, these devices will eventually degrade and need to be replaced. Keeping track of a device address and setting that same address correctly in a replacement device would be very difficult for technicians. But a Foundation fieldbus system automatically assigns addresses to all Foundation devices, avoiding the human errors associated with manually managed protocols and saving time.



Device manufacturers control how a device is displayed in a system using EDDL.

Need for calibration

In factory automation the discrete inputs predominantly come through I/O-subsystems and the outputs may be solenoid valve banks or drives. These devices need no calibration. Thus ad-hoc connection of temporary master devices like a laptop or handheld field communicator is not required. In process control systems, however, the devices are predominantly transmitters, analyzers, and valve positioners which require calibration from time to time and in some cases need to be set up in the field. Foundation fieldbus technology supports multiple masters, enabling documenting calibrators, field communicators, and laptops to be connected impromptu to a running bus for calibration, setup, diagnostics, and monitoring purposes.

Bus commonalities

Although variable speed drives, motor control centers (MCCs), and motor starters are also used in process industries, manufacturers have not made them available with the Foundation fieldbus protocol, but they are generally available with other protocols.

A process plant may therefore require the digital plant architecture to incorporate two or more communication protocols to network all the devices: Foundation fieldbus to meet the needs of PID loops; Profibus for motor control; HART for the devices on the safety instrumented system (see *Control Engineering Asia*, Jun-Jul 2009); and WirelessHART.

These four protocols achieve tight integration and interoperability the same way - using EDDL. A mix of devices based on these protocols can be managed from the same single software, to leverage the power of field intelligence for improved plant performance.

Intelligent devices contain a large amount of information, such as diagnostics of themselves as well as attached sensors and valves, plus parameters for set up of the device. Device manufacturers use IEC 61804-3 EDDL (www.eddl.org) to design device pages and the hierarchical menu system displayed in the system so the device is easy to use (see *Control Engineering Asia*, September 2007).

Device information is presented as simple text or values, as well as multi-pen trend charts, multi-pen waveform graphs, dial gauges, bar-graphs, bar-charts, tables, and histograms. The user is guided step-by-step through complex procedures using EDDL wizards. Other user guidance from the device manufacturer includes illustrative images and help text, saving time interpreting and acting on diagnostics.That is, EDDL makes bus technologies easy to use, much like HTML (hypertext markup language) in web browser technology makes the internet easy to use.

What about Ethernet?

One commercial off-the Shelf (COTS) technology that has made its way into automation is Ethernet. Ethernet networking has the advantage that it is easy to use, it's fast, and together with TCP/IP, it supports many different protocols at the same time. In fact, most bus technologies by now have a corresponding protocol for Ethernet, and some are complementing each other and others are competing among themselves just like bus technologies.

It was previously predicted the IEC 61158 standard would soon be eclipsed by Ethernet. However, it did not happen quite that way. Ethernet has indeed become a phenomenal success in automation, but at the higher control network level, not at the fieldbus level. DCS and PLC controllers are frequently networked to servers and workstations using Ethernet, but Ethernet is not used to connect field devices like transmitters and valves.

One reason is that its very high speed restricts the distance to only 100 m for copper wire. Fiber optic Ethernet reaches farther but is not as popular. Ethernet also needs LAN switches and dedicated cable to each device. This works well for controllers but becomes very costly for a large number of transmitters and valves. Fieldbus is thus a better solution for field instruments.

However, because one size does not fit all, fieldbus and Ethernet can complement each – much like the same way a computer has ports for Ethernet for connection to the higher level LAN and the Internet, plus USB to connect to underlying keyboard, mouse, digital camera, mobile phone, PDA, etc.

The same is even true for wireless in automation. High-speed wireless Ethernet IEEE 802.11 (Wi-Fi) is used for tablet PCs, and backhaul to a plant network from gateways and other devices with high data throughput. Wireless process transmitters on the other hand use WirelessHART based on IEEE 802.15.4 for smaller data volume, designed specifically to conserve power enabling transmitters to operate on batteries for several years. WirelessHART and Wi-Fi standards complement each other in the industry just as Bluetooth and Wi-Fi complement each other at home and in the office.

A wireless field network is pure digital communication which can be used where running a bus to instruments is costly or impractical. Just as for bus technologies, there are different ways to do wireless depending on the requirements to be met.

Rather than competing as was initially envisaged, fieldbus and Ethernet networks complement each other in today's plants.

Standards lessons

One thing we learned from the fieldbus standardization effort is that industry consortia like the HART Communication Foundation,

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Fieldbus Foundation, and PNO (for Profibus) can keep up with technology developments thanks to frequent meetings and shorter review periods than larger standardization bodies. They can therefore complete their work sooner, before the national and international standards are written and approved. Once the development work is done, the standards organization approves the ready technology.

The so-called "fieldbus wars" were focused mainly on the data link layer of the protocol. For wireless field networks the there will be no "fight" on which is the best physical layer and data link layer. It is already clear that it is IEEE 802.4.15, and for higher level networks it will be the IEEE 802.11 family of standards. Because of their different requirements, wireless for factory automation is likely to be different from the wireless in process control.

For wireless technologies the differentiation will be at the "application layer". WirelessHART uses the same commands as wired HART, trusted by manufacturers and users alike because of the interoperability provided over more than a decade.

WirelessHART is currently the only interoperable protocol for wireless field networks and is fast becoming the de-facto standard as one manufacturer after another announces products based on this standard and support in control systems. Many plants have already adopted WirelessHART for their wireless field network infrastructure. IEC standardization is progressing and has already achieved status as IEC/PAS 62591.

Throughout the plant

Adoption of fieldbus has moved fastest for "complex" devices like drives and electric actuators that previously required many signal wires. Leading corporations are using fieldbus for devices throughout plants including control valves, analyzers, and transmitters. EDDL makes bus technologies easier to use by integrating multiple protocols in the same software to manage all devices from a single location, presenting essential device information "on top", providing user guidance, and step-by-step wizards.

Interoperability between a broad array of fieldbus products from different manufacturers has improved greatly thanks to ever more rigorous testing of devices and systems. Over the past 10 years, many refinements have been made to the different fieldbus technologies, products, and systems, including simpler solutions for hazardous areas, specialized troubleshooting tools, and engineering guidelines. **CEA**

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